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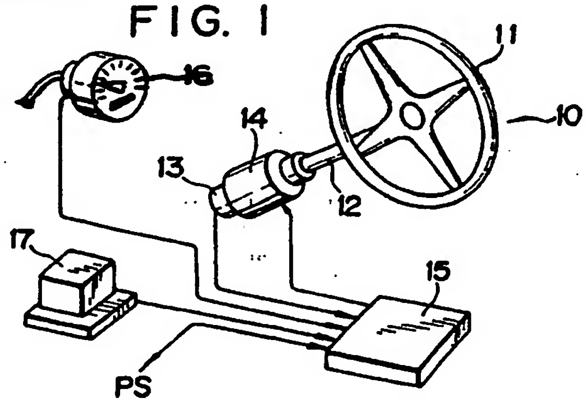
(54) **Steering system for motor vehicle.**

(57) A steering system [10] for a motor vehicle having power steering means [PS] including an actuator for turning steerable road wheels of the motor vehicle includes a control mechanism [PS] for eliminating a deviation [θe] between a desired direction [θs; $K \cdot \theta s$] of travel of the motor vehicle and an actual direction [ψ; $Kn \cdot \psi$] of travel of the motor vehicle, based on an output signal from a direction indicating mechanism [11, 13] which indicates the desired direction [θs; $K \cdot \theta s$] and an output signal from a direction detecting mechanism [17, 15] which detects the actual direction [ψ; $Kn \cdot \psi$]. The control mechanism [15] determines a target turning angle [$Ks \cdot \theta e$] for the steerable road wheels dependent on the deviation [θe] between the desired direction [$K \cdot \theta s$] and the actual direction [$Kn \cdot \psi$], and controls the power steering mechanism [PS] to turn the steerable road wheels up to the target turning angle [$Ks \cdot \theta e$].

FIG. 1



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STEERING SYSTEM FOR MOTOR VEHICLE

The present invention relates to a steering system for use in a motor vehicle.

Conventional steering systems for motor vehicles or the like include mechanical components such as gears, links, and the like which operatively interconnect a steering wheel and steerable road wheels. Steering action of the steering wheel is transmitted via the mechanical components to the steerable road wheels to turn the road wheels through an angle dependent on a steering angle θs of the steering wheel. In such a steering system, the steering angle θs represents a desired amount (or a desired angle) by which the motor vehicle is to be turned from a reference direction of the motor vehicle (i.e., a straight running direction of the motor vehicle). Therefore, where the steering angle θs is zero, the motor vehicle runs along a straight course without changing its direction of travel.

When a motor vehicle 200 is to change lanes as shown in FIG. 6A of the accompanying drawings, the steering angle θs varies as shown in FIG. 6B while the resultant direction R2 of travel is the same as the initial direction R1 of travel. More specifically, when the motor vehicle 200 starts changing lanes, the steering wheel thereof (not shown) is turned in one direction (to the right in FIG. 6B) from a neutral position ($\theta s = 0$). When the motor vehicle 200 goes beyond a lane separating line L, the steering wheel is turned in the opposite direction (to the left) beyond the neutral position. When the motor vehicle 200 enters the desired other lane, the steering wheel is turned again in said one direction to allow the motor vehicle 200 to run straight, and then is returned to the neutral position.

When the motor vehicle 200 makes a 90°-turn along a road bend around a corner as shown in FIG. 7A, the resultant direction R3 of travel of the motor vehicle 200 is angularly shifted 90° clockwise from the original direction R1 of travel. At this time, the steering angle θs varies as shown in FIG. 7B. At the start of making the turn, the steering wheel is turned in one direction (to the right in FIG. 7B) from the neutral position. When the motor vehicle 200 completes the 90°-turn, the steering wheel is turned in the opposite direction (to the left) back to the neutral position.

For steering the motor vehicle equipped with the above steering system, the driver may apply, as one steering input, a steering angle θs as a basis for producing a turning angle δ of a steerable road wheel (e.g., a front wheel turning angle δf), to the steering system. The behavior of the motor vehicle while it is making a turn is greatly affected by lateral motion (transverse motion) and yawing. While the motor vehicle is making a stable turn, the lateral acceleration $\ddot{y}$ of the motor vehicle, a yaw rate (yaw angular velocity) r, and the radius R of the turning circle are related to the turning angle δ (here, the front wheel turning angle δf) and the vehicle speed V as follows:

$$\ddot{y} = \frac{1}{1 + Kf \cdot V^2} \cdot \frac{V^2}{\ell} \cdot \delta f \qquad \cdots (1)$$

$$r = \frac{1}{1 + Kf \cdot V^2} \cdot \frac{V}{\ell} \cdot \delta f \qquad \cdots (2)$$

$$R = (1 + Kf \cdot V^2) \cdot \frac{\ell}{\delta f} \qquad \cdots (3)$$

where ℓ: the wheelbase, and

Kf: the stability factor indicative of the response of the motor vehicle.

As can be understood from the above equations (1), (2), and (3), in order to get a desired turning behavior of the motor vehicle, the driver is required to achieve an appropriate turning angle δf by giving a steering angle θs) in view of the vehicle speed V.

When the speed of movement of the motor vehicle is high, and the lateral slip angle of the tires is large, the cornering forces produced by the tires become nonlinear. In such a case, the stability factor Kf is also varied as it is affected by the transient characteristics. Therefore, the driver is also required to turn the steering wheel while taking into account such a change in the stability factor Kf.

It is an object of the present invention to provide a steering system for steering a motor vehicle in a desired direction through a relatively simple steering action.

According to the present invention, there is provided a steering system for a motor vehicle having

power steering means including an actuator for turning steerable road wheels of the motor vehicle, said steering system comprising: direction indicating means for indicating a desired direction of travel of the motor vehicle with respect to a reference direction of the motor vehicle; direction detecting means for detecting an actual direction of travel of the motor vehicle; and control means responsive to an output signal from said direction indicating means and an output signal from said direction detecting means for controlling said power steering means to eliminate a deviation between said desired direction and said actual direction based on said output signals.

According to the present invention, there is also provided a steering system for a motor vehicle having power steering means including an actuator for turning steerable road wheels of the motor vehicle, said steering system comprising: direction indicating means for indicating a desired direction of travel of the motor vehicle with respect to a reference direction of the motor vehicle; direction detecting means for detecting an actual direction of travel of the motor vehicle with respect to said reference direction; target turning angle determining means responsive to an output signal from said direction indicating means and an output signal from said direction detecting means for calculating a deviation between said desired direction and said actual direction based on said output signals, and for determining a target turning angle for the steerable road wheels dependent on said deviation; and control means responsive to an output signal from said target turning angle determining means for controlling said power steering means to turn said steerable road wheels up to said target turning angle.

The above and further objects, details and advantages of the present invention will become apparent from the following detailed description of a preferred embodiment thereof, when read in conjunction with the accompanying drawings.

FIG. 1 is a schematic perspective view of a steering system for a motor vehicle according to a preferred embodiment of the present invention;

FIG. 2 is a block diagram of the steering system;

FIG. 3 is a graph showing functional characteristics of the steering system;

FIG. 4 is a graph showing steering reactive force characteristics in the steering system;

FIGS 5A and 5B are block diagrams showing functional blocks of the steering system;

FIGS 6A through 6C are diagrams illustrating how a steering amount varies when a vehicle changes lanes; and

FIGS. 7A through 7C are diagrams showing how a steering amount varies when a vehicle makes a turn.

As shown in FIGS. 1 and 2, a steering system 10 for a motor vehicle according to the present invention has a steering wheel 11 (direction indicating means) fixedly mounted on the upper end of a steering shaft 12 rotatably supported on a vehicle body (not shown). The steering shaft 12 is mechanically separate from steerable road wheels (not shown), and an encoder 13 and a reactive force generator 14 (reactive force applying means) including an electric motor (not shown) are mounted on the lower end of the steering shaft 12. The encoder 13 and the reactive force generator 14 are electrically connected to a controller 14 (control means) comprising a microcomputer and other electronic devices. The encoder 13 detects the angular displacement of the steering shaft 12 and applies a signal indicative of a steering angle θs to the controller 15. The electric motor of the reactive force generator 14 is controlled by the controller 15, as described later on, to apply a steering reactive force T to the steering shaft 12, i.e., the steering wheel 11 as it is turned.

When the steering wheel 11 is turned, the steering reactive force T is applied to the steering wheel 11 by the reactive force generator 14. Since the steering wheel 11 is mechanically disconnected from the steerable road wheels, as described above, a self-aligning torque generated by the steerable road wheels when they are turned is not imposed on the steering wheel 11. In addition, the steering wheel 11 is not biased to rotate in either direction. As a consequence, the steering wheel 11 tends to stay in whatever position it may have been stopped by the driver of the motor vehicle.

In the motor vehicle equipped with the steering system 10, the steering angle θs is regarded as being zero when the steerable road wheels (e.g., front road wheels) are directed in a straight running direction. A front wheel steering angle δf, for example, is varied dependent on a change in the steering angle θs, as described below, to control the direction of travel of the motor vehicle or its angle (i.e., yaw angle ψ) so as to achieve a desired direction or angle.

To the controller 15, there are electrically connected a speedometer 16, a yaw rate gyroscope 17 (direction detecting means), and a power steering mechanism PS. The speedometer 16 applies a signal indicative of a vehicle speed V to the controller 15. The yaw rate gyroscope 17 applies a signal representing a yaw rate r (yaw angular velocity r) of the motor vehicle to the controller 15. The power

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steering mechanism PS has an electric motor (not shown) for producing a steering force, and a gear mechanism (not shown) disposed between the electric motor and the steerable road wheels. The controller 15 energizes the electric motor of the power steering mechanism PS to turn the steerable road wheels. The controller 15 processes signals from the encoder 13, the speedometer 16, and the yaw rate gyroscope 17 according to a predetermined program, and controls the electric motor of the reactive force generator 14 to apply the steering reactive force to the steering wheel 11 and also controls the electric motor of the power steering mechanism PS to turn the steerable wheels. The power steering mechanism PS is disclosed in Japanese Patent Application No. 62-331084 (331084/1987) filed December 26, 1987 by the applicant.

Operation of the steering system 10 will be described below with reference to FIGS. 2, 3, and 4.

The controller 15, in particular, of the steering system 10 has functions as shown in FIG. 2. The steering angle θs of the steering wheel 11 is basically representative of a desired direction in which the motor vehicle should run, with respect to a reference direction of travel of the motor vehicle (i.e., the direction in which the motor vehicle runs at the time).

First, the steering angle θs is multiplied by a gain constant K to determine a converted indicated angle $K \cdot \theta s$. The yaw rate r is integrated to determine the yaw angle ψ of the motor vehicle from time to time. The yaw angle ψ is multiplied by a gain constant Kn to determine a converted running angle $Kn \cdot \psi$ of the motor vehicle with respect to the reference direction. Then, the running angle $Kn \cdot \psi$ subtracted from the indicated angle $K \cdot \theta s$ to calcu late a deviation θe therebetween. The deviation θe is multiplied by a gain constant Ks to determine a target turning angle $Ks \cdot \theta e$ for the steerable road wheels. Since the gain constant Ks for obtaining the target turning angle $Ks \cdot \theta e$ is a function of the vehicle speed V as described later on, the gain constant Ks varies with the vehicle speed V. If the vehicle speed V is constant, then the gain constant Ks is also constant, and the target turning angle $Ks \cdot \theta$ is proportional to the deviation θe. The steerable road wheels are turned up to the target turning angle $Ks \cdot \theta e$ by the power steering mechanism PS to cause the motor vehicle to make a turn. The turning motion of the motor vehicle varies the yaw rate r and also the converted running angle $Kn \cdot \psi$ of the motor vehicle which has been calculated by the aforesaid integrating and multiplying process. In this manner, the steerable road wheels are turned until the running angle $Kn \cdot \psi$ reaches the indicated angle $K \cdot \theta s$ while feeding back the converted running angle $Kn \cdot \psi$ from time to time.

At the same time that the steerable road wheels are turned, the steering reactive force T is applied to the steering wheel 11 by the reactive force generator 14. The steering reactive force T is basically of such a characteristic that it increases as the deviation θe increases. The steering reactive force T also increases as the vehicle speed V increases, as described later.

Through the above functions, the steerable road wheels are continuously turned transitionally with a characteristic dependent on the deviation θe, until finally the converted running angle $Kn \cdot \psi$ of the motor vehicle reaches the indicated angle $K \cdot \theta s$. Even if the turning behavior of the motor vehicle is temporarily affected by a disturbance such as a lateral wind or the like, the final running angle $Kn \cdot \psi$ of the motor vehicle is reliably achieved. Therefore, the running angle $Kn \cdot \psi$ of the motor vehicle can reach the indicated angle $K \cdot \theta s$ simply by turning the steering wheel 11 to give the desired indicated angle $K \cdot \theta s$. As a consequence, the desired vehicle running angle $K \cdot \theta s$ can be attained through relatively simple steering action.

More specifically, when the motor vehicle having the steering system 10 changes lanes as shown in FIG. 6A, the steering angle θs varies as illustrated in FIG. 6C. With the steering system 10, the lanes can be changed only by a steering action effected on one side of a temporary neutral position, and hence it is not necessary to effect a steering action on both sides of the neutral position as with the conventional steering system as shown in FIG. 6B.

When the motor vehicle having the steering system 10 makes a 90°-turn as shown in FIG. 7A, the steering angle θs varies as shown in FIG. 7C. With the steering system 10, when the turn is completed, the steering wheel 11 is kept in the position to which it has been turned, and does not need to be returned to the neutral position as with the conventional steering system as shown in FIG. 7B.

FIGS. 5A and 5B illustrate functional blocks of the steering system 10.

According to the functions shown in FIG. 2, the deviation θe is determined as follows:

$\theta e = K \cdot \theta s - Kn \cdot \psi$ (4)

The target turning angle $Ks \cdot e$ is determined on the basis of the deviation θe.

All of the gain constants K, Kn, Ks, and Kp are functions of the vehicle speed V, and vary with the vehicle speed V.

By dividing both sides of the equation (4) by θs, the following equation is obtained:

$\theta e/\theta s = K - Kn \cdot \psi/\theta s$ (4')

Inasmuch as the gain constants K, Kn are constant if the vehicle speed V is constant, the lefthand side ($\theta e/\theta s$) of the equation (4') indicates a normalized deviation or normalized input Nd, whereas the term $\psi/\theta s$

on the righthand side indicates a normalized output No. From another standpoint, the lefthand side ($-\theta e/\theta s$) of the equation (4′) represents the sensitivity of the deviation θe to the steering angle θs, and the term $\psi/\theta s$ on the righthand side represents the sensitivity of the yaw angle ψ to the steering angle θs.

For example, if the gain constants K, Kn in the equation (4′) are set so as to vary as described below, then characteristic curve groups Ga, Gb, and Gc indicated by the solid lines, the dot-and-dash lines, and the broken lines in FIG. 3 are obtained. It is assumed, however, that the vehicle speed V increases in increments.

• Group Ga:

The gain constant K for the steering angle θs: K = 1, i.e., it is constant regardless of the vehicle speed V;

The gain constant Kn for the yaw angle ψ: this increases in proportion to the vehicle speed V.

In the group Ga, the gain Kn for the yaw angle ψ increases in proportion to the vehicle speed V. Therefore, the higher the vehicle speed V, the higher the sensitivity with which the yaw angle ψ is detected. As a result, the rate of final change of the yaw angle ψ with respect to a unit steering angle is smaller as the vehicle speed V is higher.

With a characteristic curve L0 achieved when K = 1 and Kn = 0, since the gain constant Kn for the yaw angle ψ is zero, the yaw angle ψ is not fed back. Therefore, if the steering function is performed along the characteristic curve L0, the functional characteristics of the steering system 10 are equivalent to those of the conventional steering system in which the steering wheel and the steerable road wheels are mechanically interlinked.

• Group Gb:

The gain constants K, Kn: Both decrease in inverse proportion to the vehicle speed V.

In the group Gb, the higher the vehicle speed V, the lower the sensitivity with which the steering angle θs is applied and the sensitivity with which the yaw angle ψ is detected.

• Group Gc:

The gain constant K: this decreases in inverse proportion to the vehicle speed V;

The gain constant Kn: K = 1, i.e., it is constant irrespective of the vehicle speed V.

In the group Gc, the gain K for the steering angle θs increases in proportion to the vehicle speed V. Consequently, the higher the vehicle speed V, the lower the sensitivity with which the steering angle θs is applied. As a result, the rate of final change of the yaw angle ψ with respect to a unit steering angle is smaller as the vehicle speed V is higher.

As described above, the steering reactive force T basically increases as the deviation θe increases and also as the vehicle speed V increases. The steering reactive force T and the gain constant Kp are represented by functions $T = Kp \cdot f(\theta e)$ and $Kp = g(V)$, respectively, where V indicates the vehicle speed. The latter function has such a characteristic that the gain constant Kp increases as the vehicle speed V goes higher. Therefore, when the vehicle speed V is in a low range, a medium range, and a high range, the steering reactive force T increases respectively along characteristic curves Ltℓ, Ltm, Lth, shown in FIG. 4 as the deviation θe increases. Since an adequate reactive force is applied to the steering wheel 11 dependent on the deviation θe and the vehicle speed V, the steering action of the steering wheel 11 is stabilized, giving the driver a good steering feeling.

In the above embodiment, the gain constants K, Kn, Kp are basically functions of the vehicle speed V only. However, they may be functions of (i) a steering amount such as a steering speed of the steering wheel 11, the deviation θe, etc., or (ii) a vehicle running condition such as the speed of a lateral wind applied to the motor vehicle, etc., or their combination. The present invention is applicable also the a steering system for a motor vehicle having steerable front and rear road wheels.

A geomagnetism sensor may be employed instead of the yaw rate sensor 17 as means for detecting the actual direction of travel of the motor vehicle. Where such a geomagnetism sensor is used, the northward direction is used as an absolute reference direction.

Although there has been described what is at present considered to be the preferred embodiment of

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the present invention, it will be understood that the invention may be embodied in other specific forms without departing from the essential characteristics thereof. The present embodiment is therefore to be considered in all aspects as illustrative, and not restrictive. The scope of the invention is indicated by the appended claims rather than by the foregoing description.

Claims

1. A steering system [10] for a motor vehicle having power steering means [PS] including an actuator for turning steerable road wheels of the motor vehicle, said steering system [10] comprising:
direction indicating means [11, 13] for indicating a desired direction [θs; $K \cdot \theta s$] of travel of the motor vehicle with respect to a reference direction of the motor vehicle;
direction detecting means [17, 15] for detecting an actual direction [ψ; $Kn \cdot \psi$] of travel of the motor vehicle; and
control means [15] responsive to an output signal [θs] from said direction indicating means [11, 13] and an output signal [ψ] from said direction detecting means [17, 15] for controlling said power steering means [PS] to eliminate a deviation [θe] between said desired direction and said actual direction based on said output signals.

2. A steering system according to claim 1, further comprising indicated direction gain control means for varying a gain [K] of the output signal [θs] from said direction indicating means [11, 13].

3. A steering system according to claim 2, wherein said indicated direction gain control means comprises means for controlling said gain [K] so as to reduce the gain [K] in inverse proportion to a speed [V] of travel of the motor vehicle.

4. A steering system according to claim 1, further comprising detection gain control means for varying a gain [Kn] of the output signal [ψ] from said direction detecting means [17, 15].

5. A steering system according to claim 4, wherein said detection gain control means comprises means for controlling said gain [Kn] so as to increase the gain [Kn] in proportion to a speed [V] of travel of the motor vehicle.

6. A steering system accoridng to claim 1, further comprising:
reactive force applying means [14] for applying a steering reactive force [T] to said direction indicating means [11, 13]; and
reactive force control means [13, 15] for controling said reactive force applying means [14] to apply the steering reactive force [T] which increases in proportion to said deviation [θe] between said desired direction [θs; $K \cdot \theta s$] and said actual direction [ψ; $Kn \cdot \psi$].

7. A steering system according to claim 6, wherein said reactive force control means [13, 15] comprises means for controlling said reactive force applying means [14] to increase a rate of change [Kp] of said steering reactive force [T] with respect to said deviation [θe] in proportion to a speed [V] of travel of the motor vehicle.

8. A steering system according to claim 6, wherein said direction indicating means [11, 13] has a steering wheel [11] mechanically separate from said steerable road wheels.

9. A steering system [10] for a motor vehicle having power steering means [PS] including an actuator for turning steerable road wheels of the motor vehicle, said steering system [10] comprising:
direction indicating means [11, 13] for indicating a desired direction [θs; $K \cdot \theta s$] of travel of the motor vehicle with respect to a reference direction of the motor vehicle;
direction detecting means [17, 15] for detecting an actual direction [ψ; $Kn \cdot \psi$] of travel of the motor vehicle with respect to said reference direction;
target turning angle determining means [15] responsive to an output signal [θs] from said direction indicating means [11, 13] and an output signal [ψ] from said direction detecting means [17, 15] for calculating a deviation [θe] between said desired direction [$K \cdot \theta s$] and said actual direc tion [$Kn \cdot \psi$] based on said output signals, and for determining a target turning angle [$Ks \cdot \theta e$] for the steerable road wheels dependent on said deviation [θe]; and
control means [15] responsive to an output signal from said target turning angle determining means [15] for controlling said power steering means [PS] to turn said steerable road wheels up to said target turning angle [$Ks \cdot \theta e$].

10. A steering system [10] for a motor vehicle having steerable road wheels, comprising:
direction detecting means [17] for detecting an actual direction [ψ] of travel of the motor vehicle and producing a detected signal indicating said actual direction [ψ];
steering means [11, 12, 13] mechanically separate from said steerable road wheels for producing an

indication signal [ψs] indicating a desired direction [$K \cdot \theta s$] of travel of the motor vehicle; and control means [15, PS] responsive to said detected signal from said direction detecting means [17] and said indication signal from said steering means [11, 12, 13] for transitionally turning said steerable road wheels to bring the resultant actual direction [ψ] of travel of the motor vehicle into agreement with said desired direction [$K \cdot \theta s$] based on said detected and indication signals.

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FIG. 1

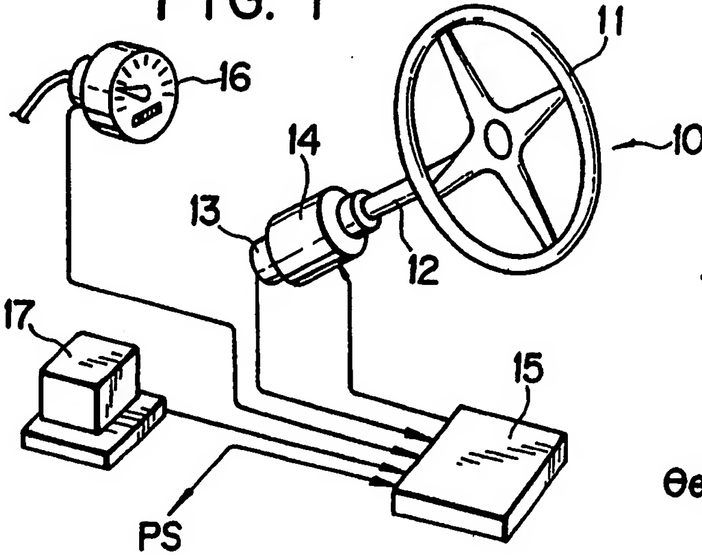

FIG. 4

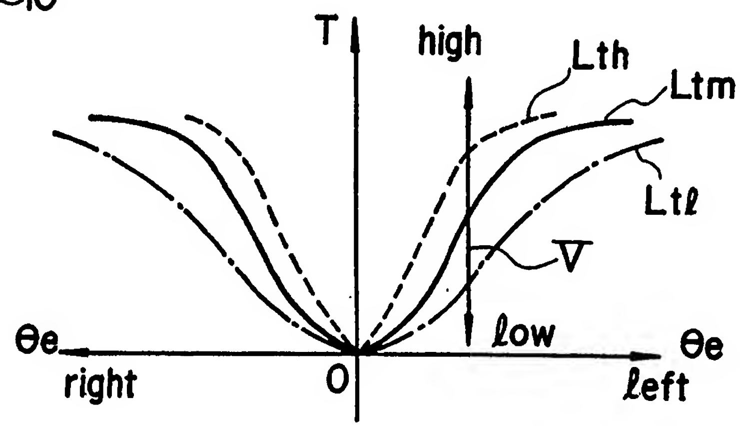

FIG. 2

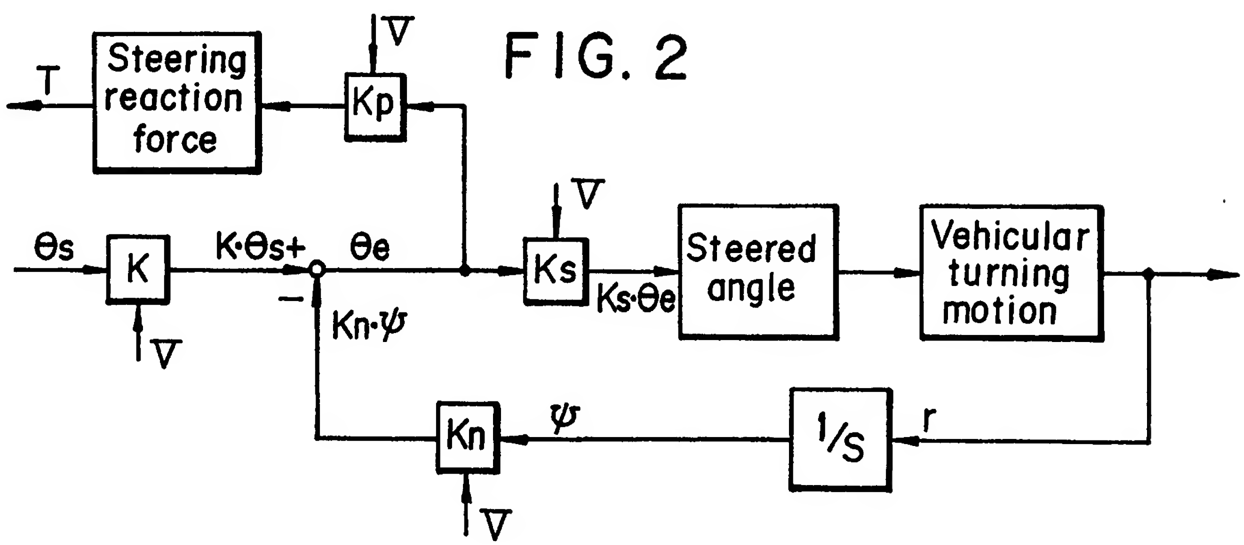

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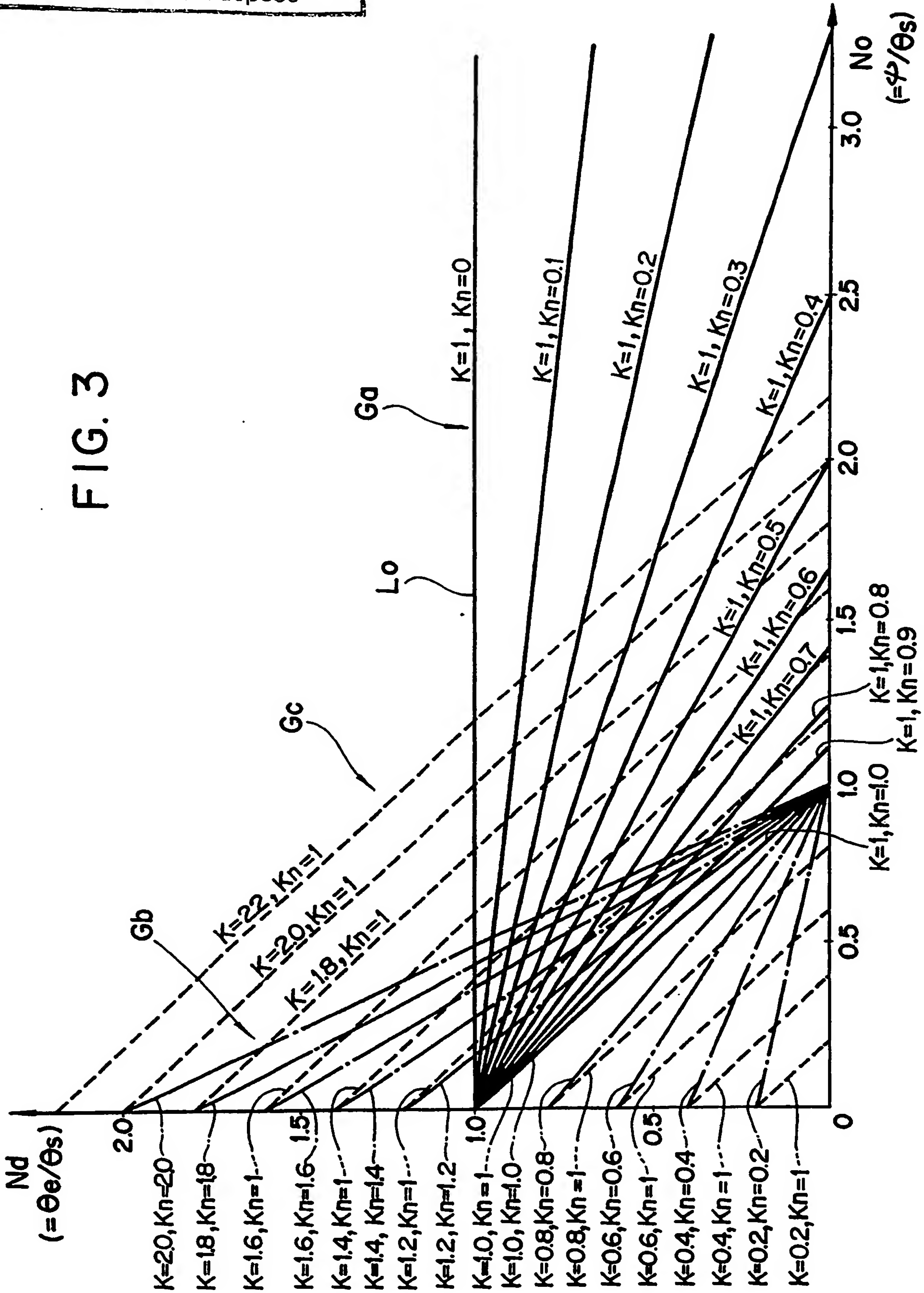
FIG. 3



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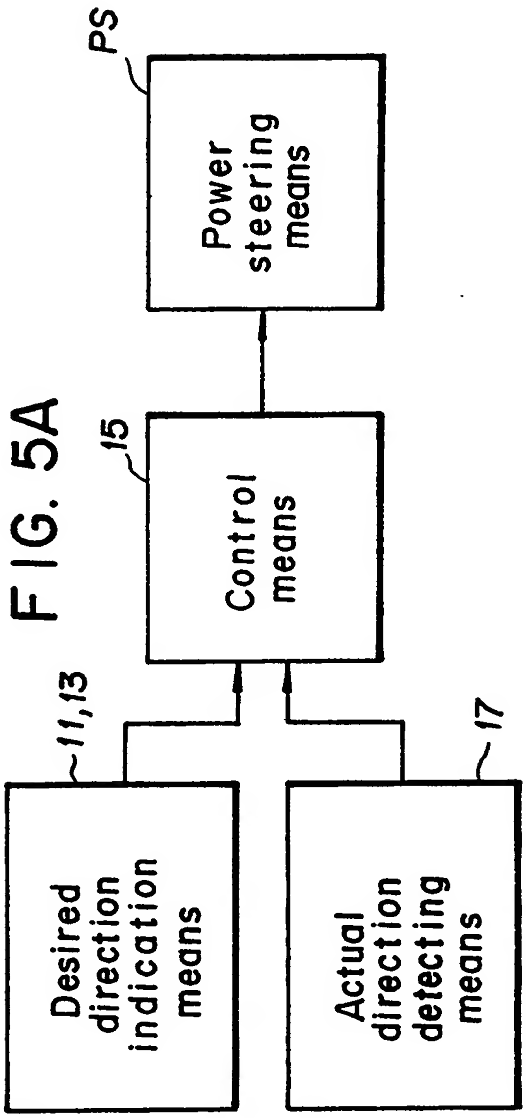


FIG. 5A

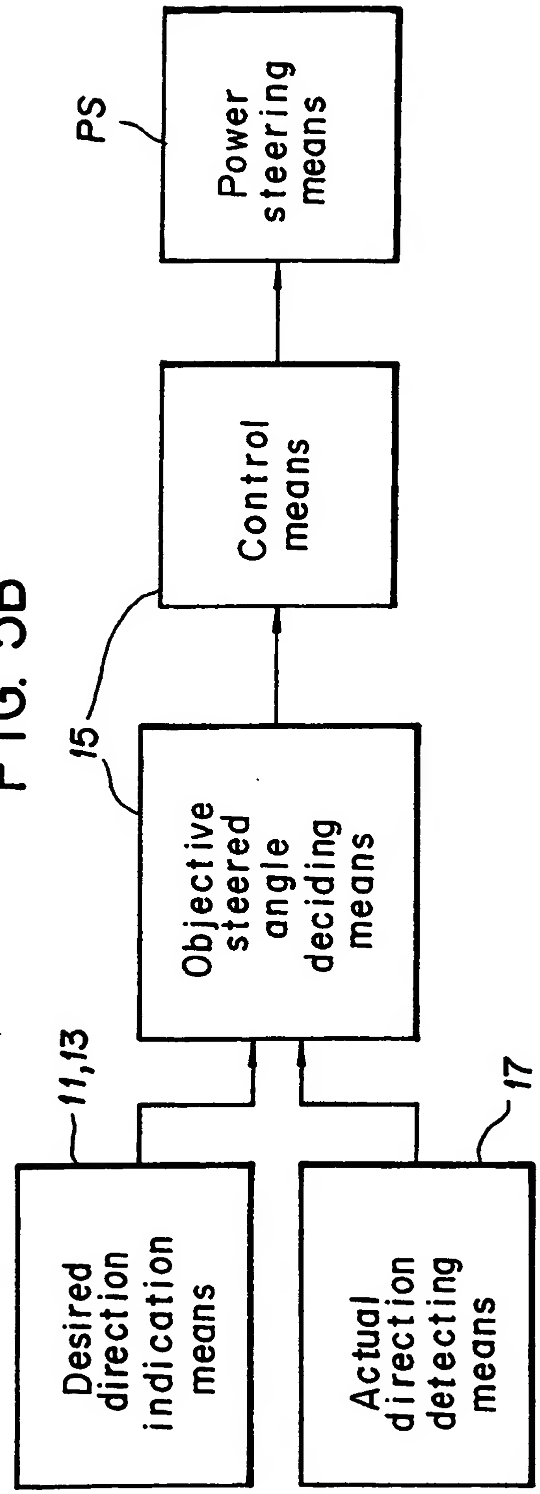


FIG. 5B

FIG.6A

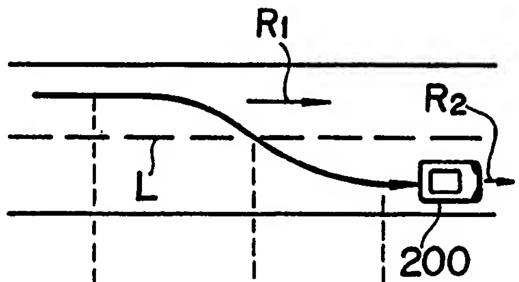


FIG.6B

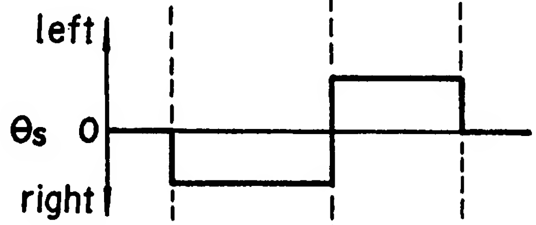


FIG.6C

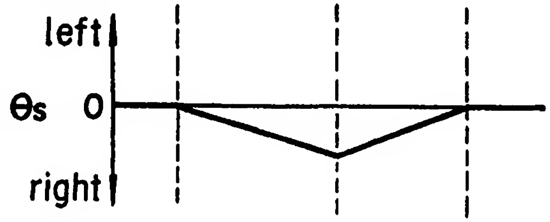


FIG.7A

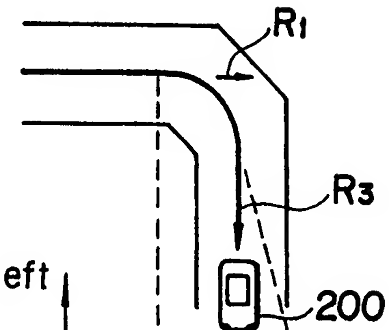


FIG.7B

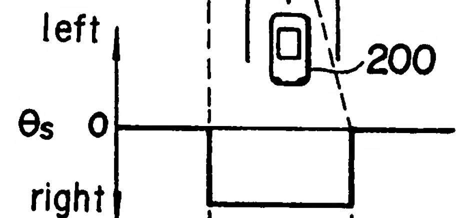
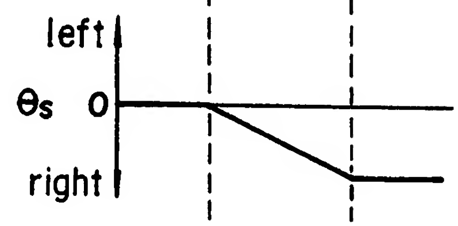


FIG. 7C



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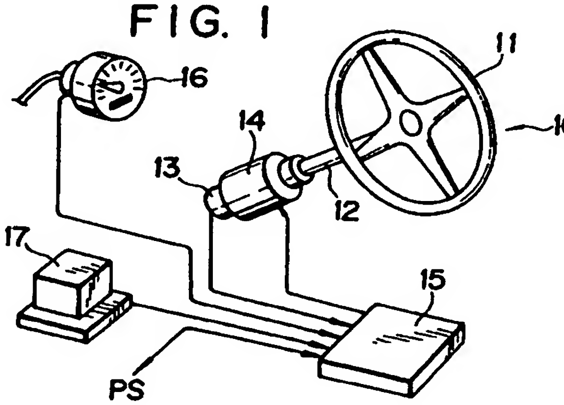
(54) Steering system for motor vehicle.

(57) A steering system [10] for a motor vehicle having power steering means [PS] including an actuator for turning steerable road wheels of the motor vehicle includes a control mechanism [PS] for eliminating a deviation [θe] between a desired direction [θs; $K \cdot \theta s$] of travel of the motor vehicle and an actual direction [ψ; $Kn \cdot \psi$] of travel of the motor vehicle, based on an output signal from a direction indicating mechanism [11, 13] which indicates the desired direction [θs; $K \cdot \theta s$] and an output signal from a direction detecting mechanism [17, 15] which detects the actual direction [ψ; $Kn \cdot \psi$]. The control mechanism [15] determines a target turning angle [$Ks \cdot \theta e$] for the steerable road wheels dependent on the deviation [θe] between the desired direction [$K \cdot \theta s$] and the actual direction [$Kn \cdot \psi$], and controls the power steering mechanism [PS] to turn the steerable road wheels up to the target turning angle [$Ks \cdot \theta e$].

FIG. 1



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